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No. 995

THE CREEP OF LAMINATED SYNTHETIC RESIN PLASTICS

By H. Perkuhn

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TECHNICAL MEMORANDUM NO. 995

THE CREEP OF LAMINATED SYNTHETIC RESIN PLASTICS*

By H. Perkuhn

SUMMARY

The long-time loading strength of a number of laminated synthetic resin plastics was ascertained and the effect of molding pressure and resin content determined. The best value was observed with a 30 to 40 percent resin content. The long-time loading strength also increases with increasing molding pressure up to 250 kg/cm^2; a further rise in pressure affords no further substantial improvement.

The creep strength is defined as the load which in the hundredth hour of loading produces a rate of elongation of 5×10^{-4} percent per hour. The creep strength values of different materials were determined and tabulated (table 2).

The effect of humidity during long-time tests is pointed out.

INTRODUCTION

If plastics are stressed so highly that they can be used at about the same weight for construction as metal unusually high deformations can occur at the comparable stresses permissible for metals in aircraft design, depending upon the kind of stress and the design of the structural part. The deformations will be high because of the low elastic modulus of plastics and the incipient creep under protracted loads even for low stresses. The effect of time on the deformation - the plastic and the elastic portion - of laminated synthetic resin plastics even at room temperature is already comparable to that of metal structures at high temperatures such as do not occur under normal service conditions.

*"Kriechverhalten geschichteter Kunstharzpress-stoffe." Luftfahrtforschung, vol. 18, no. 1, Feb. 28, 1941, pp. 32-37.

The scope of experimentation on creep is not very extensive (reference 1).

A description of creep tests on laminated plastics prepared at various molding pressures and with different resin content, together with suggestions for improving the creep behavior of such plastics is given as follows:

Plastics under load manifest considerable creep even at room temperature, as exemplified in Müller's experiments with pure plastics (reference 2).

The deformation processes on laminated plastics are more complicated because of the existence of a very non-homogeneous and anisotropic structure.

EXPERIMENTAL SET-UP

The experiments were made on the fatigue-testing device shown in figures 1 and 2, which permitted testing of 16 samples at once. The specimens were loaded by weights (1) and lever (2) with an arm ratio of 1:6. The levers are mounted on ball bearings and carry balance weights with coarse and fine adjustment (3), (4). Clamping the test specimens in spherically mounted clamping heads (5) with wedge grips insures a centrally applied load. The shock-free application of the load is insured by the tension springs (6) and the lowering of the load by means of a spindle (7). The elongations were recorded with a Fuess cathetometer (fig. 1). The instrument rotates about a vertical axis and is disposed in the center with the test specimens arranged in a half circle. Its recording accuracy is ±0.01 mm. The arrangement of the clamping grips permitted deformation measurements with other strain instruments as well.

To maintain constant temperature (20° C) a thermostat mounted on a level with the specimens controlled an electric stove. In a similar manner a hygrostat and an electric water evaporation system equalized the differences in atmospheric moisture.

TEST PROCEDURE

The study included:

1. Paper-laminated plastics

a) DVL plastic, molded from 0.6 mm thick soda pulp sheets. Resin content: 9 percent, 31 percent, and 44 percent (in relation to weight of plastic).

b) Plastics, commercial papier-mâché

c) Z3A plastics, molded from 0.25 mm thick impregnated paper sheets, 31 percent resin content

d) Z3F plastics, the test specimens being taken from a molded structural part of an airplane.

2) Fabric-laminated plastics of cotton fabric weighing 66 g/m^2, resin content 22 percent, 38 percent, and 51 percent.

The binder for the plastics under la)and 2 was phenol-formaldehyde resin brushed on the resin carrier. Plastics la, lc, and 2 were molded between 200×90 or 200×40 mm platens in an 80-t press at 60, 200, and 600 kg/cm^2 molding pressure and 145° C temperature. The specimens, the shape of which is shown in figure 3, were taken from 200×90×1.2 and 200×40×1.2 mm plates for materials la, lc, and 2, from 1000×1000×1.2 mm plates for material lb, and from a molded aircraft part for material ld.

The measurements were made at 20 ± 1° C temperature and 70 percent ± 1.5 percent relative humidity.

The elongations were measured with a cathetometer (±1/100 mm) and in the low-load range with a dial precision gage (test length 50 mm, magnification 1:50). Through the experiments the following values were determined.

1. Long-time loading strength in relation to

a) Molding pressure

b) Resin content

The tests lasted for 30 days. The long-time loading strength was defined as the stress which could be sustained for at least 30 days without failure.

2. Strain-time curves corresponding to the long-time loading strength.

The elongations were recorded during an 185-hour load period and subsequent 185-hour unloading period.

3. Creep strength.

The creep under load was observed for different stress during 185-hour, 500-hour, and 700-hour tests. After load removal the creep behavior was followed for a time corresponding to the loading period.

TEST RESULTS

Figures 4 to 7 give the time elapsed to cause failure for paper-laminated and fabric-laminated plastics under various stresses. The long-time loading strength defined as the stress which is withstood at least 30 days without failure ranges between 50 to 75 percent of the tensile strength for a given material, depending upon resin content and molding pressure. All curves exhibit a marked drop in stress within a comparatively short loading period. For 2-day loading the strength of all the materials is on the average nearly 40 percent lower than in a tensile test with 800 kg/cm^2/min rate of loading. After a 10-day loading period no appreciable stress decrease is noticeable.

1a) Long-Time Loading Strength in Relation to Molding Pressure

According to figure 8 the long-time loading strength of Z3A increases considerably with increasing pressure up to about 250 kg/cm^2, but a further rise in molding pressure affords no marked improvement in strength.

1b) Long-Time Loading Strength in Relation to Resin Content

The long-time loading strength shows the same dependence upon resin content as the breaking stress in the tensile test with uniformly increasing load (reference 3) (fig. 8b). In both the paper-laminated and the fabric-laminated plastics the strength increases with increasing resin content. The best values range between

30 and 40 percent resin content, while an increase beyond 40 percent is followed by a drop in strength again.

The principal results are reproduced in table 1.

2. Strain-Time Curves for the Stress Corresponding to the Long-Time Loading Strength (fig. 9)

All the materials manifested at this load total elongations (1.2 to 2.5 percent) far in excess of the amount permitted in engineering structures. The permanent strains alone after 190 hours of loading exceed 0.2 percent. The strain-time curves disclose a lasting decrease in the rate of strain but without reaching zero. For the purpose of answering the question as to whether the test specimens break in finite time, the time-strain curves of figure 9 were replotted in a semilogarithmic coordinate system. All the time-strain curves of figure 10 are concave toward the strain axis, that is, danger of failure exists within a finite time. But the elongation remaining upon release of the load disappears within comparatively short time according to figure 9.

3. Creep Strength

The definition of the creep strength postulates for every material the knowledge of the rate of creep at a given time. The evaluation of the time-strain curves for determining the creep strength was carried out, using the relations described by F. Gentner (reference 4).

In the determination of the creep strength two fundamental types of time-strain curves should be distinguished (fig. 11). Following an initially similar concave course toward the time axis the rate of strain of type (a) assumes zero value in finite time, and the strain stops. On curves of the type (b) the rate of strain decreases continuously without, however, reaching the value zero. So, while curves of type (a) are in each instance located in a safe range, the materials characterized by the time-strain curves of group (b) can sooner or later lead to failure, depending upon the speed of elongation.

Gentner shows how the aspect of the curves of type (b), when plotted in a semilogarithmic system of coordinates (time log on axis of abscissa) discloses whether danger of failure exists in finite time.

Accordingly, time-strain curves do not result in failure in a finite time interval.

1. If they are concave (hyperbolas) toward the time axis in the semilogarithmic system of coordinates

2. If they are straight (logarithmic curves)

3. If they start concave but subsequently tend to straight lines asymptotically (logarithmic curves).

The danger of failure in finite time exists, however, for curves concave toward the axis of elongation (parabolas).

Figures 12 to 15 show the time-elongation curves of synthetic resin plastics under different loads. Depending upon the magnitude of the applied stress, curves with parabolic or logarithmic shape are readily distinguished. In the long-time tests (700 hours, fig. 12) the applied stresses produce a parabolic curve throughout the entire time interval. These stresses would therefore produce failure in finite time. The limiting stresses corresponding to the creep strength and which satisfy the conditions outlined under (3) precisely, are shown in figures 13 to 15.

Following the finding of these limiting stresses the shape of the time-elongation curves was again determined at a 5 percent higher load and it was ascertained that these loads resulted in parabolic curves. Since a scatter of ±5 percent must be allowed for synthetic resin plastics, the stress value found initially determines the creep strength with sufficient accuracy.

Next, the time-elongation curves were examined with a view to predicting their subsequent shape from the creep rate at specific times. Four specimens were tested, each with different loads near the creep strength, and the time-elongation curves (figs. 16 to 18) determined. The rate of creep was determined for the time interval from the 40th to the 185th hour of loading and plotted against the load (figs. 19-21).

Then the rate of creep for different loading periods was obtained from these curves on the basis of a specified load. For the previously found limiting stresses the rate of creep in the 100th hour of loading amounted to about 5×10^{-4} percent per hour for the three different materials.

According to figures 16 to 18 it becomes apparent that after 100 hours the rate of creep has decreased suf-

ficiently that this loading period is suitable for determining the creep strength.

On the basis of these considerations the creep strength of laminated plastics was defined as the stress which in the 100th to the 110th hour interval of loading produces a rate of creep of 5×10^{-4} percent per hour. Furthermore, the permanent elongation after 110th hour loading and subsequent 24 hour relaxation must not exceed 0.2 percent. This last condition is still met by the materials in question even after a 190-hour load period. Since shorter load periods yield less elongation, this condition is particularly well satisfied for 110 hour loading.

Table 2 contains the experimental values obtained. For practical application the previously described method is very useful for predicting the creep strength. Given the rate of elongation permissible for a specified load period the creep strength can be ascertained with three to four samples; while the prediction of the creep strength by the first method is less suitable because of the greater number of tests and longer time required to determine the limiting value.

Duplicate tests were made on one plastic with a view to determining the amount of scatter to be expected in the long-time tests; the results of an extreme case are shown in figure 23. This scatter is primarily due to the fact that the structure of laminated synthetic plastics is microscopically neither homogeneous nor isotropic. Additional tests are necessary for a more accurate analysis of the elongation differences.

TABLE 2.- CREEP STRENGTH OF VARIOUS PAPER-LAMINATED PLASTICS

Material	Tensile strength (kg/cm^2)	Creep strength		In percent of tensile strength
		Gentner (kg/cm^2)	On basis of 5×10^{-4} percent of rate of creep in 100th hour of loading (kg/cm^2)	
Paper-laminated plastics, DVL	2038	720	715	30.1
Paper-laminated plastics, Z3A	2175	602	600	27.6
Paper-laminated plastics, commercial	1310	296	290	22.2

The tests disclosed that both the temperature and the atmospheric humidity affected the flow process of the plastics. Rising humidity augments the deformations, while decreasing humidity is accompanied by a shrinkage of the test specimens. Evidently, plastics are very susceptible to humidity effects in the stressed and strained state.

Translation by J. Vanier,
National Advisory Committee
for Aeronautics.

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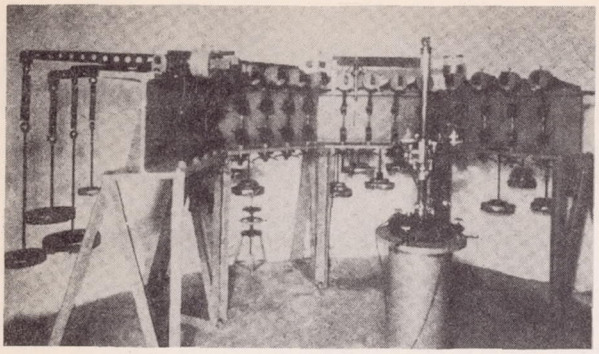
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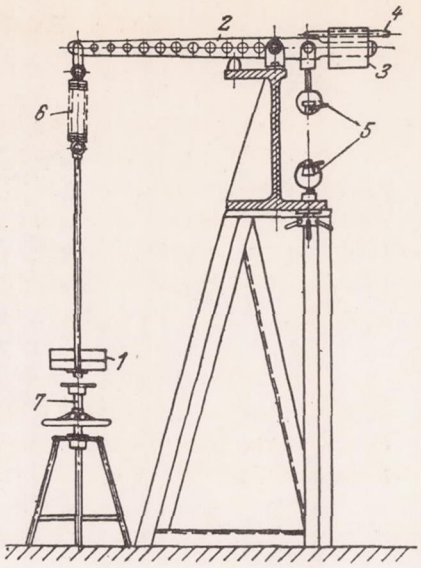
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Figures 1 and 2.- DVL creep testing apparatus for plastics.

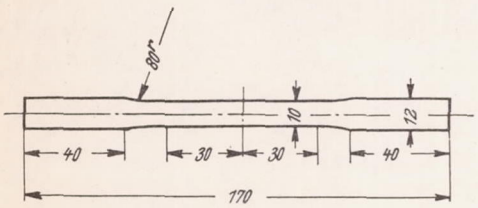


Figure 3.- Test specimen thickness 1.2 mm.

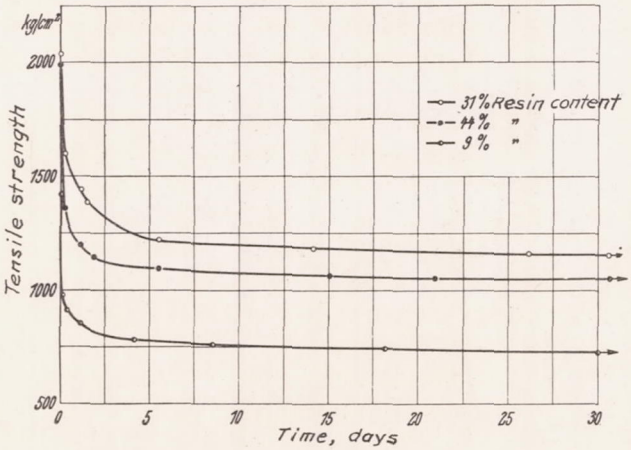


Figure 4.- Long-time loading strength of DVL paper-laminated plastics with different resin contents.

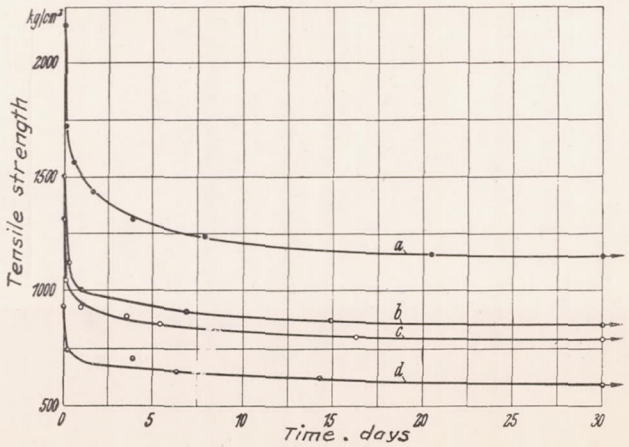


Figure 5.- Long-time loading strength of paper-laminated plastics Z 3.
(a) Paper-laminated plastics Z 3 A.
(b) Molded paper-laminated plastics.
(c) Commercial paper-laminated plastics.
(d) Paper-laminated plastics, Z 3 A No. 5690.

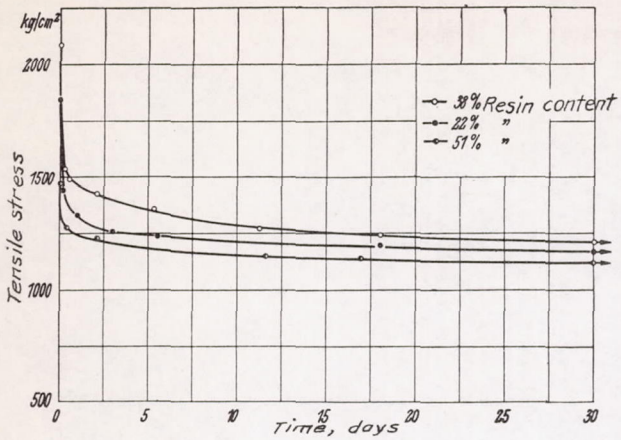


Figure 6.- Long-time loading strength of fabric-laminated plastics (DVL) with different resin content.

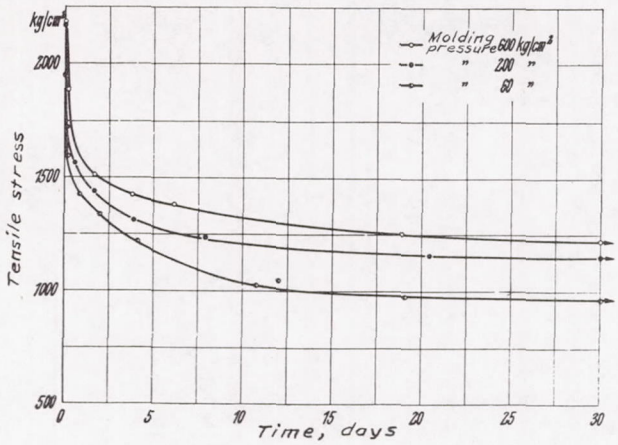


Figure 7.- Stress-time curves of paper-laminated plastics Z 3 A at different molding pressures.

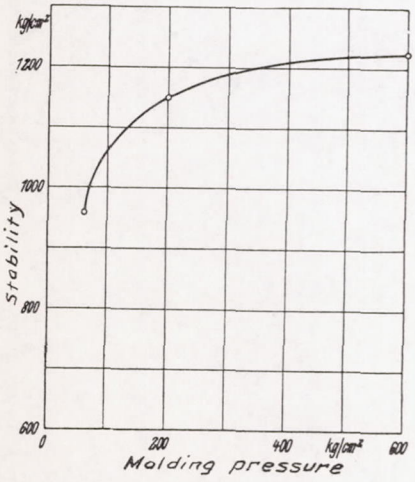


Figure 8a.- Long-time loading strength of Z 3 A as a function of molding pressure.

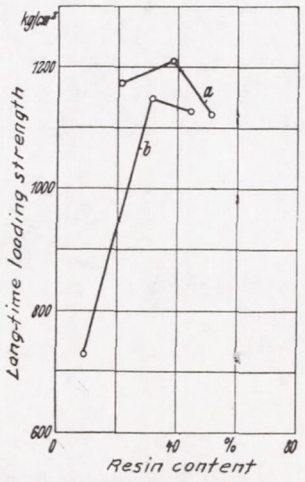


Figure 8b.- Long-time loading strength as a function of resin content.
(a) Fabric-laminated plastics (DVL).
(b) Paper-laminated plastics (DVL).

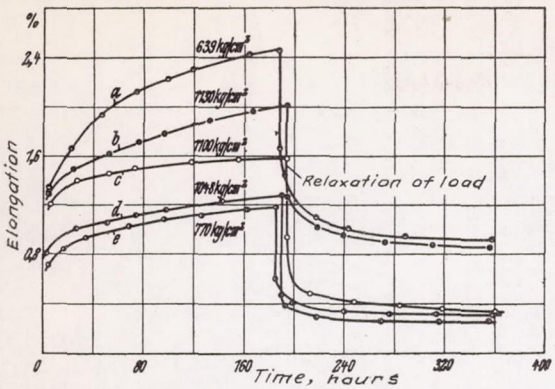


Figure 9.- Strain-time curves at loads corresponding to the long-time loading strength.
(a) Commercial paper-laminated plastics.
(b) Paper-laminated plastics Z 3 A.
(c) Fabric-laminated plastics DVL.
(d) Paper-laminated plastics DVL.
(e) " " " airplane structural part.

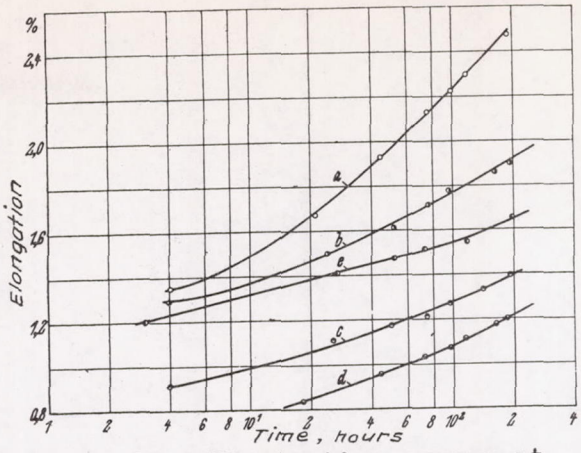


Figure 10.- Strain-time curves at loads of around 50% of that of the tensile strength.
(a) Commercial paper-laminated plastics.
(b) Paper-laminated plastics Z 3 S.
(c) " " " DVL.
(d) " " " airplane structural part.
(e) Fabric-laminated plastics DVL.

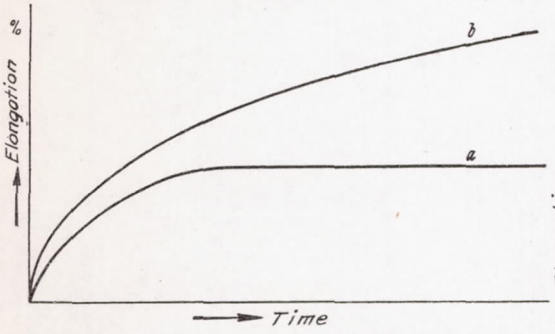


Figure 11.- Two possible types of time-strain curves.

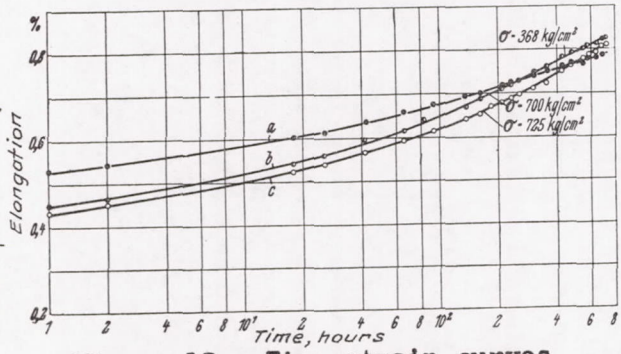
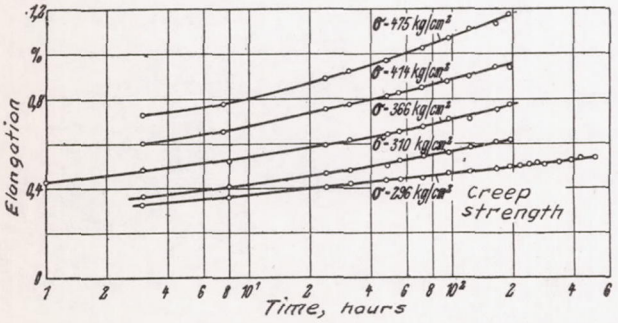


Figure 12.- Time-strain curves (long time test).
(a) Paper-laminated plastics DVL.
(b) " " " airplane structural part.
(c) Paper-laminated plastics Z 3 A.



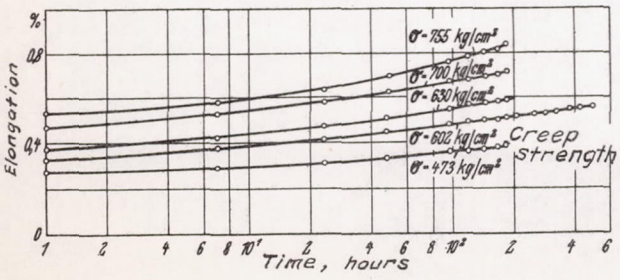


Figure 13.- Time-strain curves of commercial paper-laminated plastics.

Figure 14.- Time-strain curves of paper-laminated plastics Z 3 A.

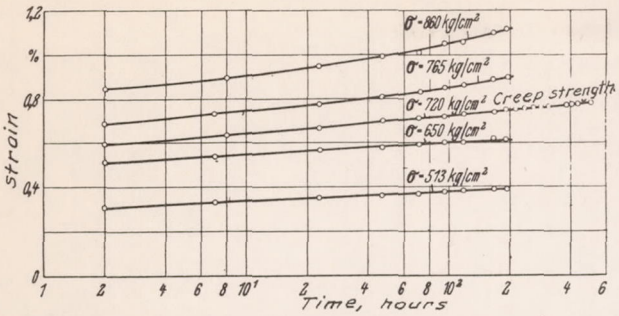


Figure 15.- Time-strain curves for paper-laminated plastics DVL.

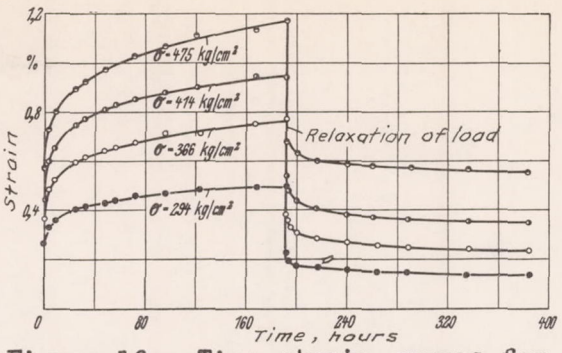


Figure 16.- Time-strain curves for commercial paper-laminated plastics.

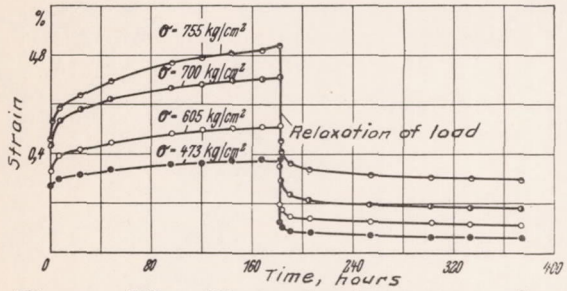


Figure 17.- Time-strain curves for paper-laminated plastics Z 3 S.

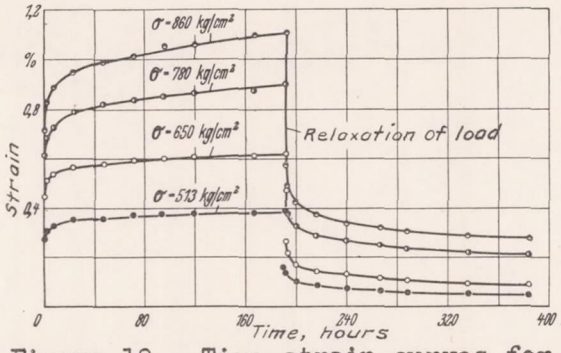


Figure 18.- Time-strain curves for paper-laminated plastics DVL.

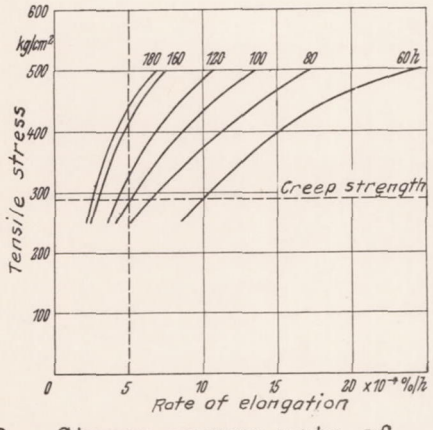


Figure 19.- Stress versus rate of creep at different loading times for commercial paper-laminated plastics.

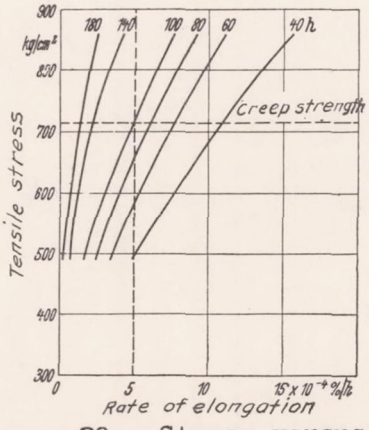


Figure 20.- Stress versus rate of creep at different loading times for paper-laminated plastics Z 3 A.

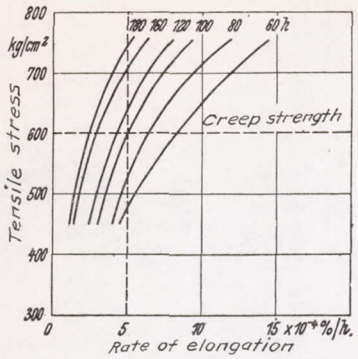


Figure 21.- Stress versus rate of creep at different loading times for paper-laminated plastics DVL.

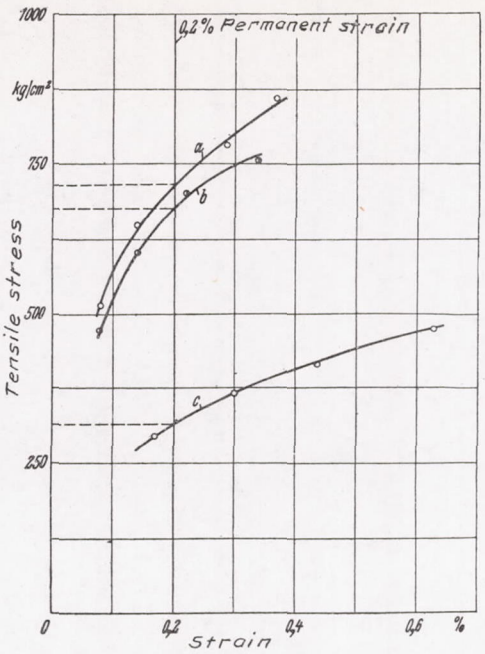


Figure 22.- Stress remaining after 190 hours loading followed by 24 hours relaxation.

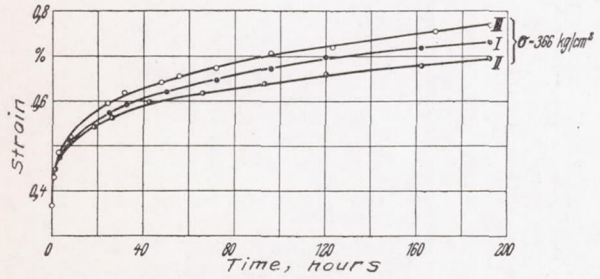


Figure 23.- Strain-time curves of commercial paper-laminated plastics for 3 different specimens at the same load.

(a) Paper-laminated plastics DVL.
(b) " " " Z 3 A.
(c) " " " Commercial.

Table I. Long-time loading strength of synthetic resin plastics.

Material	Resin Content %	Molding pressure kg/cm²	Tensile strength kg/cm²	Long-time loading strength kg/cm²	Long-time loading strength in % of tensile strength
Paper-laminated plastics DVL	9	200	1420	725	51
» » »	31	200	2038	1155	56,5
» » »	44	200	1990	1050	53
» » Z 3 A	31	200	2175	1145	52,5
» » Z 3 A	31	60	1953	944	48
» » Z 3 A	31	600	2180	1230	56,5
» » Z 3 A No. 5690.	48	200	930	590	63,5
» » (Commercial) .	—	—	1310	790	60
Paper-filled plastics (Moulded). .	—	—	1498	850	57
Fabric-laminated plastics DVL	22	200	1840	1170	63,5
» » »	38	200	2085	1210	58
» » »	51	200	1470	1120	76,5